

Applications of Computed Tomography to Evaluate Cellular Solid Interfaces

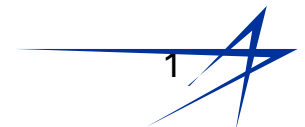
**ASNT Digital Imaging Conference XI
July 2008**

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LA 70148



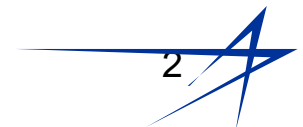


Applications of Computed Tomography to Evaluate Cellular Solid Interfaces



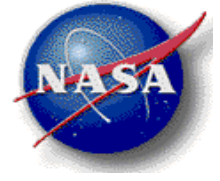
Purpose

- **Microfocus X-ray Computed Tomography (micro-CT) was utilized to investigate the interfacial cellular morphology between two closed cell rigid foams integral to the thermal protection system on The United States Space Shuttle's External Tank**
- **Investigate feasibility of micro-CT as a means to measure:**
 - **Cellular morphology**
 - **Void content**
 - **Volume of adhesive bond between polyurethane and polyisocyanurate**
- **Design strength models based on reliable morphological measurements made using micro-CT**





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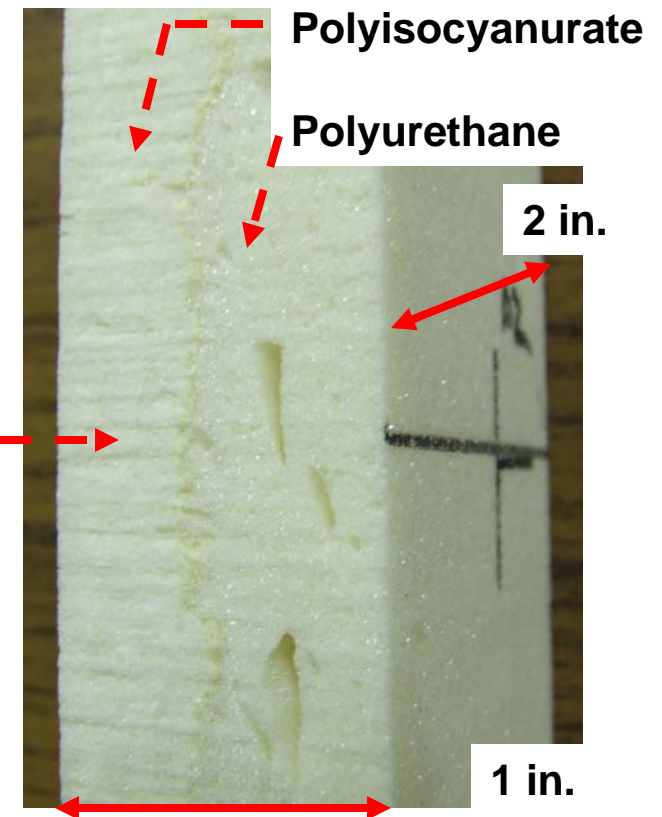
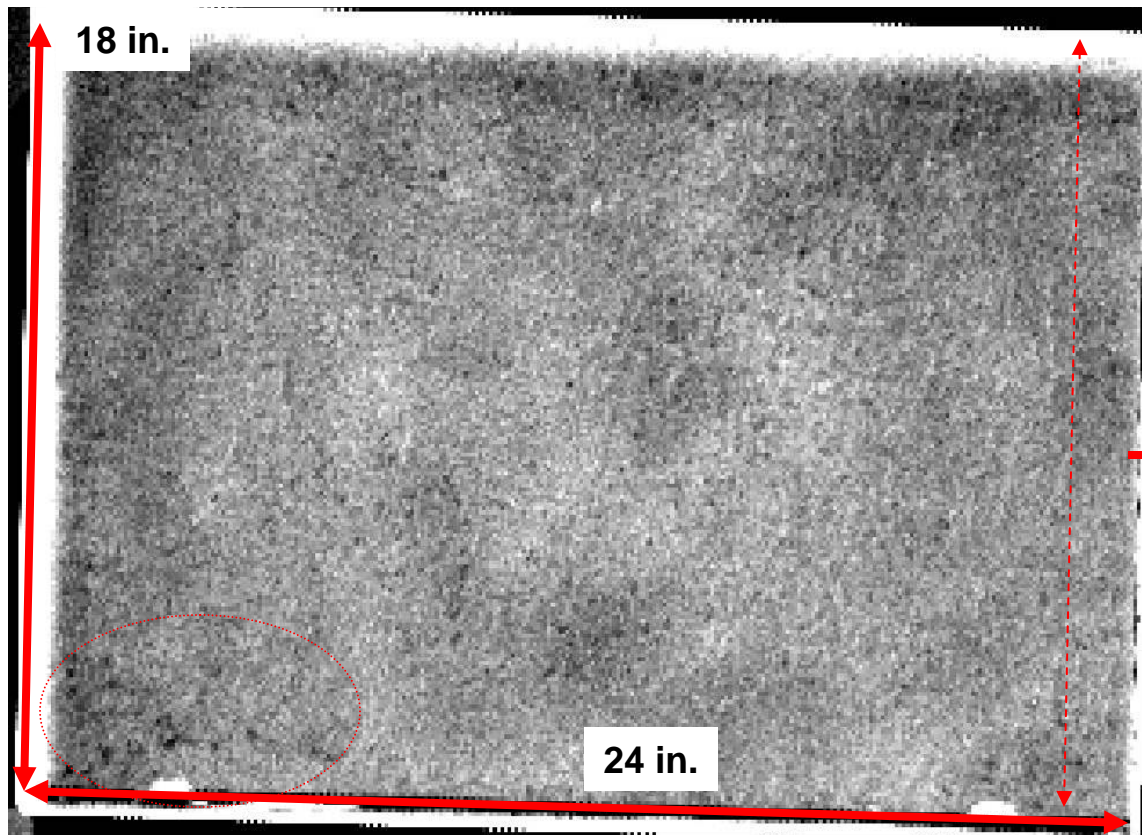
Thermal Protection System Failures on the External Tank

- Popcorning of polyisocyanurate
- Polyisocyanurate failures near/at polyurethane bondlines



Nondestructive Testing of as Received Sample Blanks

- Initial panel size: 24 in. x 18 in.
- Selected regions machined into 2 in. wide strips

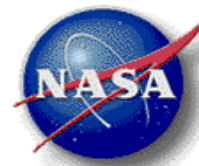


Backscatter Image of 24 in. x 18 in. panel
 55kV, 20mA, 2 mm Aperture, Pixel Size = 2mm x 2mm
 Exposure Time = 0.2 s/pixel, Focal Spot: 5.5 mm

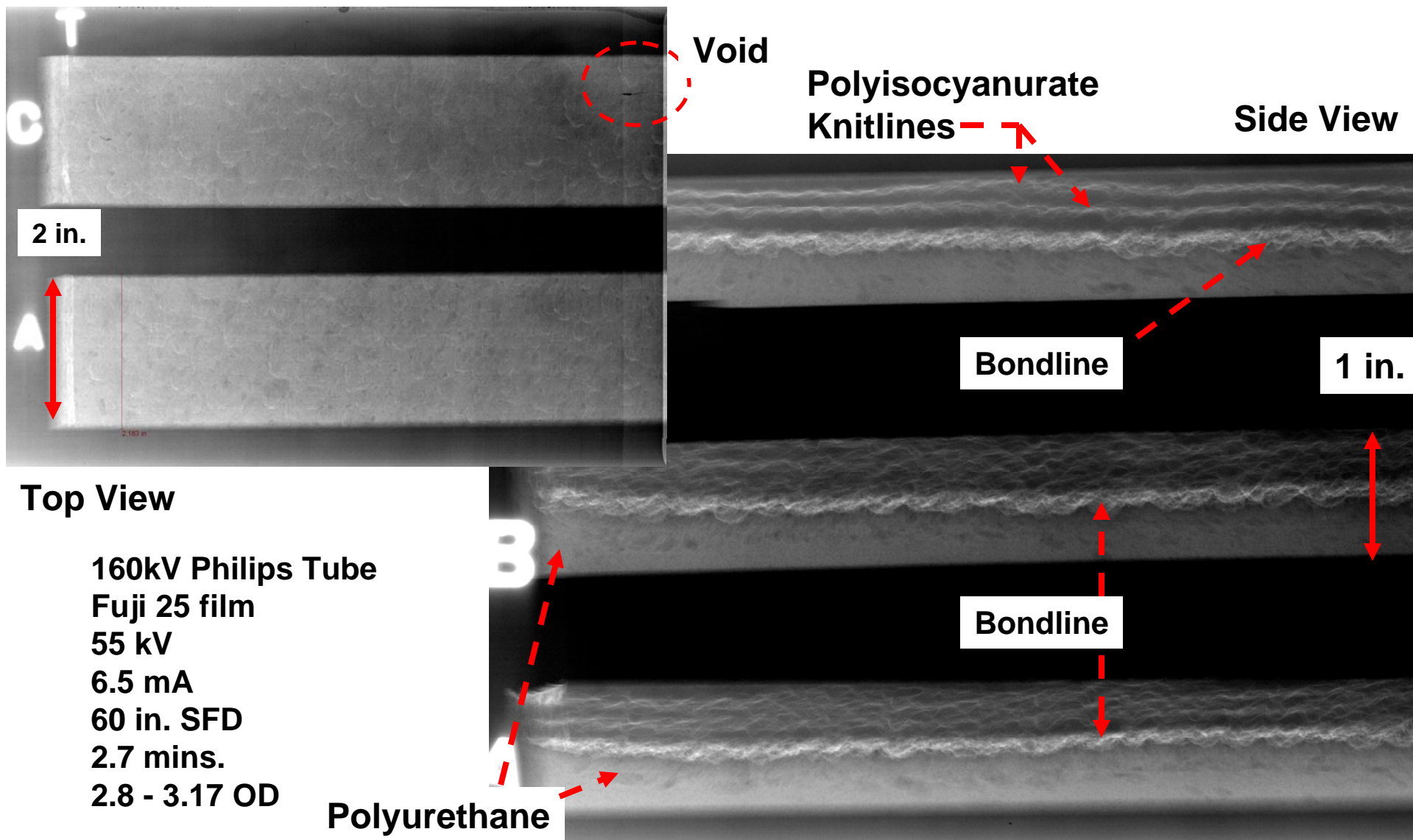
Side View



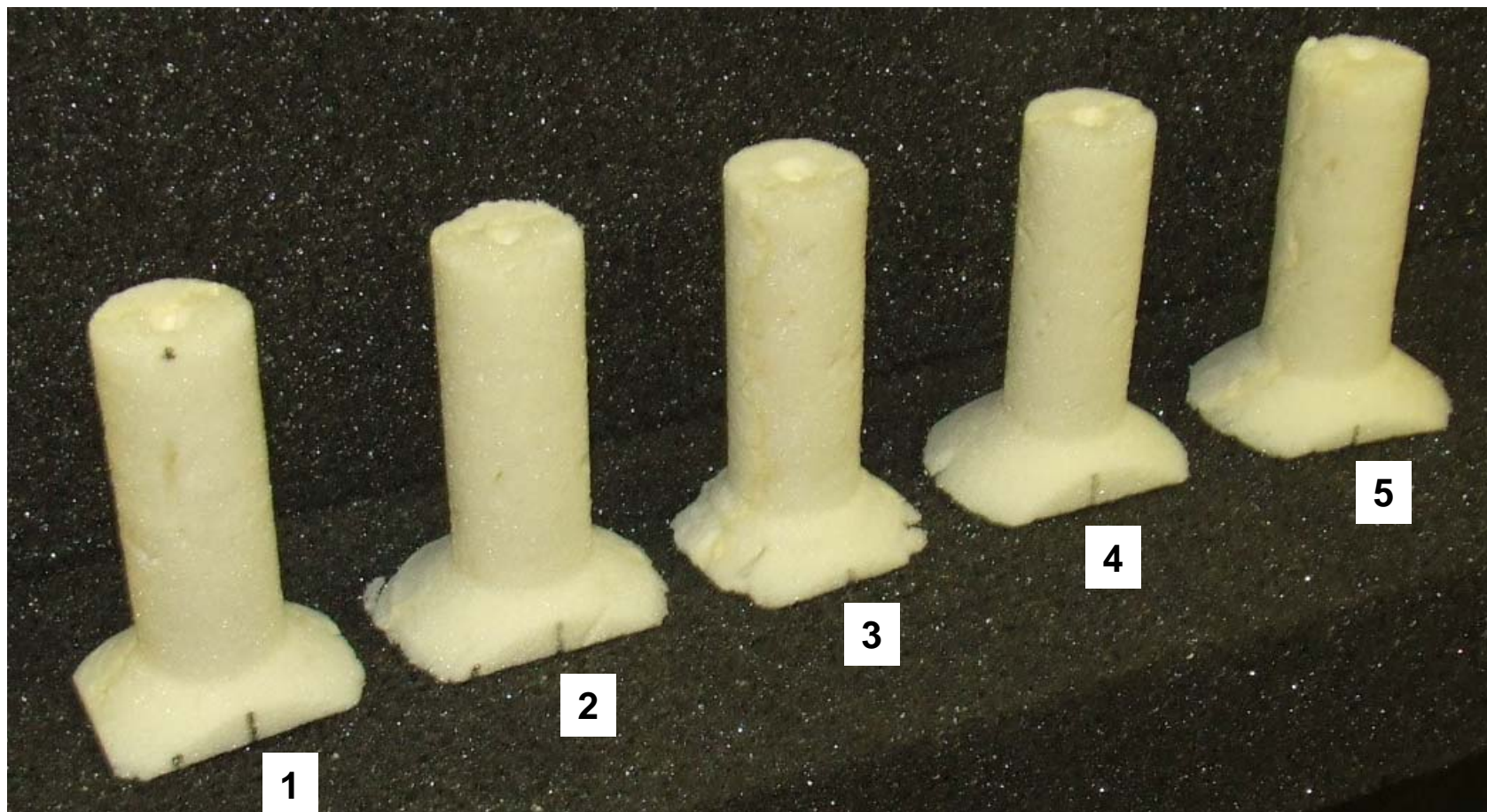
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Radiography of Sample Blanks after NDE Prescreening



Micro-CT Samples for Final NDE Prescreening



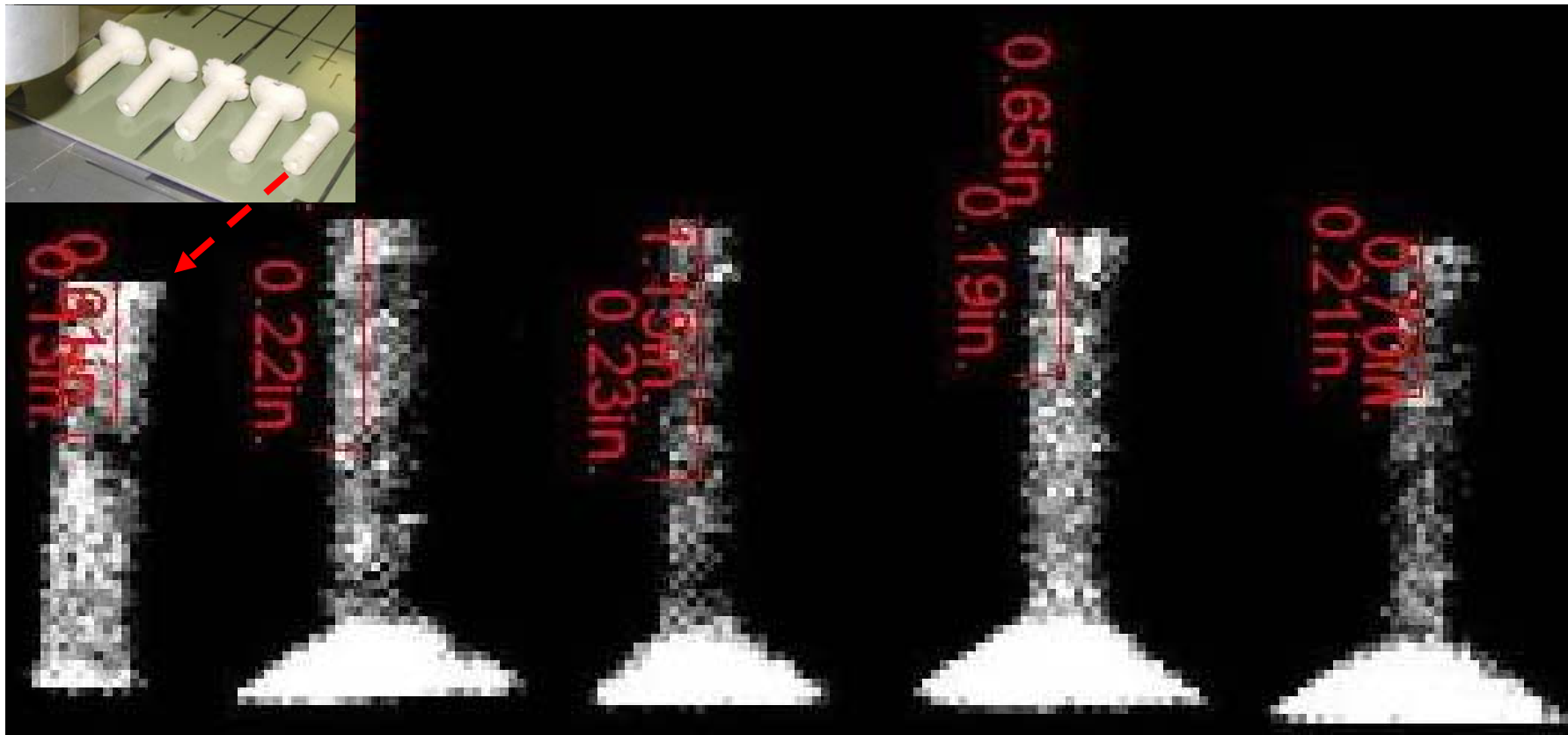
Sample ID



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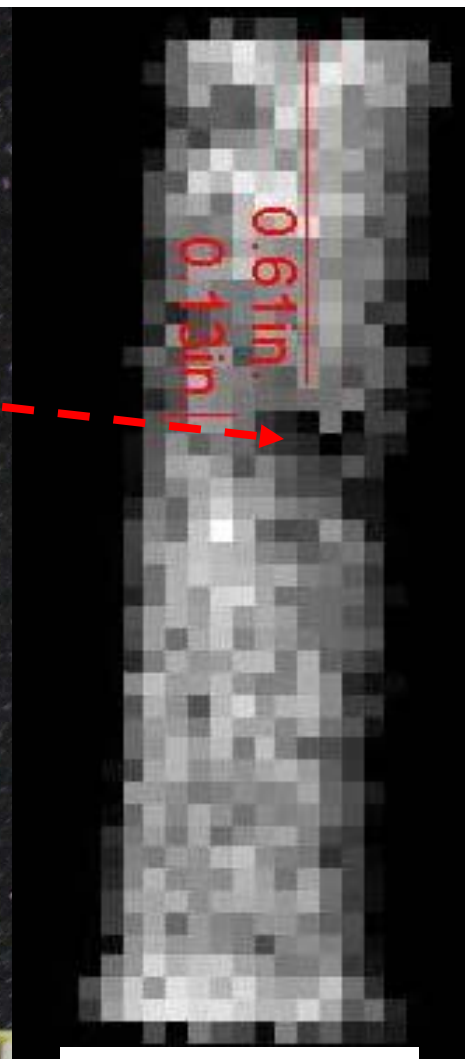
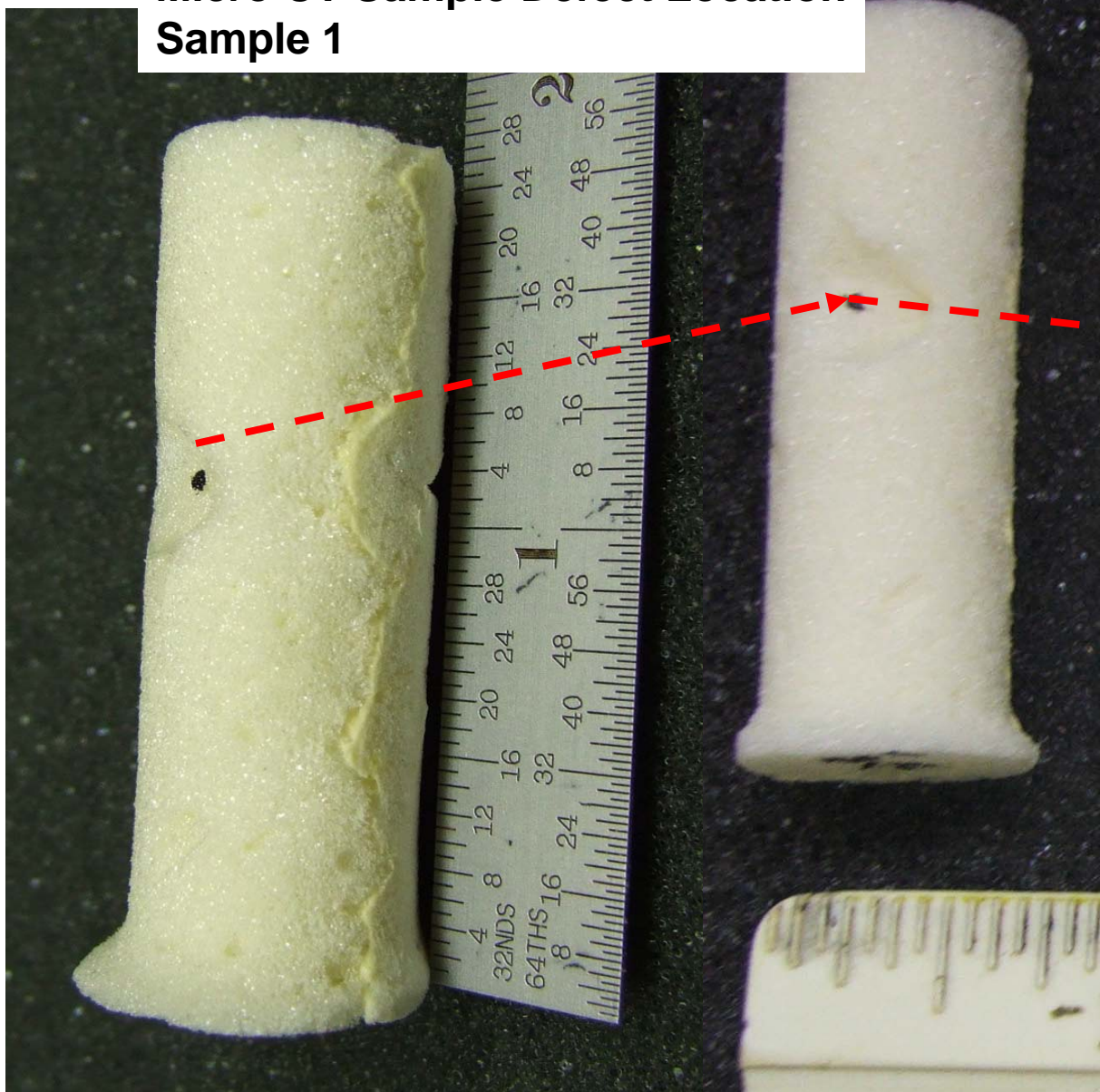
Backscatter Radiographic Image of Micro-CT Samples



- Location of selected indication was mapped for each sample prior to final machining
- Backscatter image processed using X-Ray GUI Software
- 55 kV, 20 mA, Aperture: 1 mm, Pixel Size: 1 mm x 1 mm, Focal Spot: 5.5 mm, Exposure Time: 0.2 s/pixel



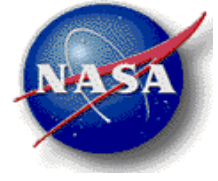
Micro CT Sample Defect Location Sample 1



Backscatter
Radiographic
Image

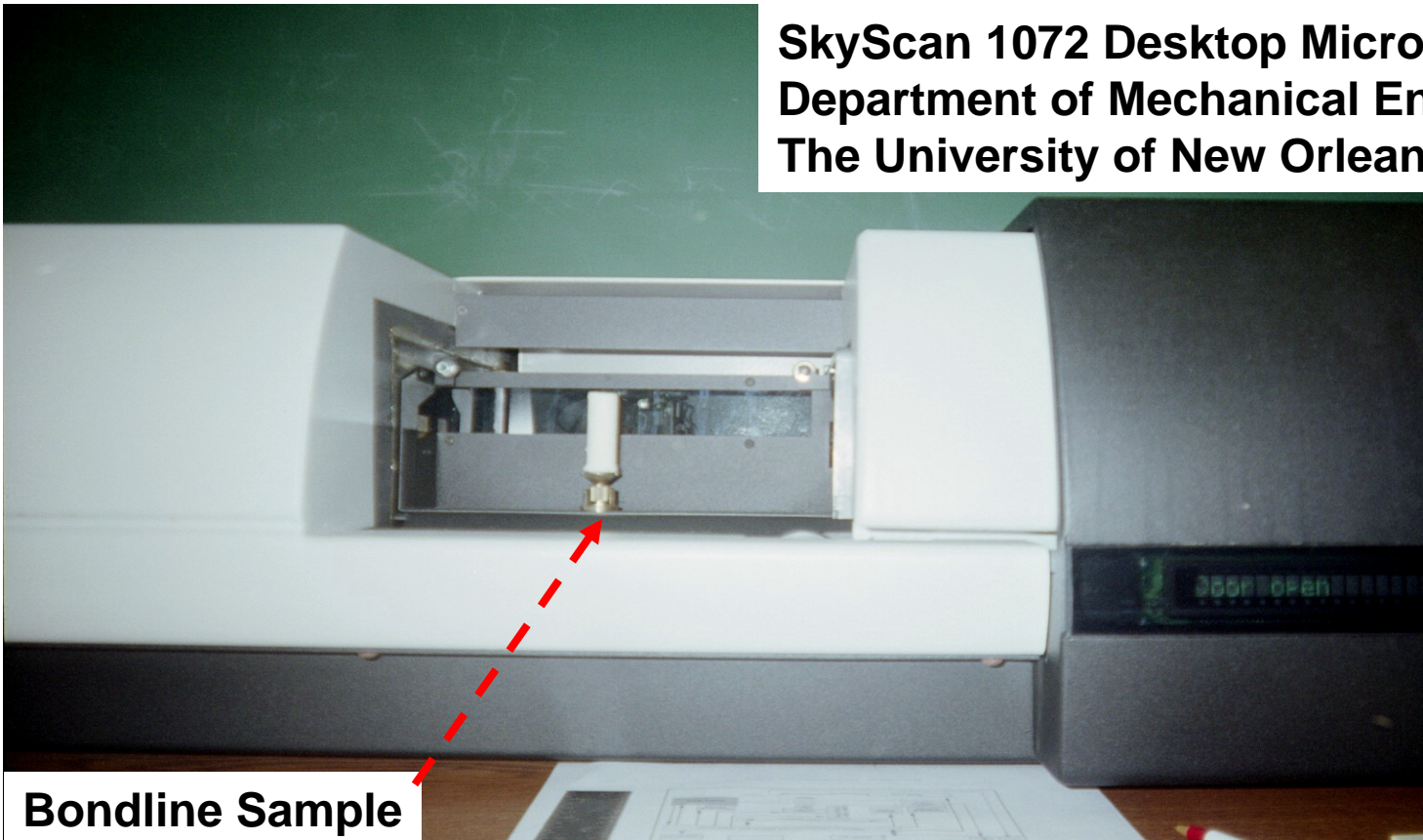


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Micro-CT Test Parameters

- 100kV
- 98 μ A
- Mag = 14.4 x
- Pixel Size: 19.5 mm x 19.5 mm

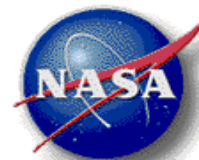


SkyScan 1072 Desktop Microscanner
Department of Mechanical Engineering
The University of New Orleans

Bondline Sample

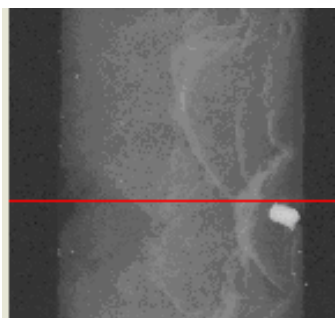
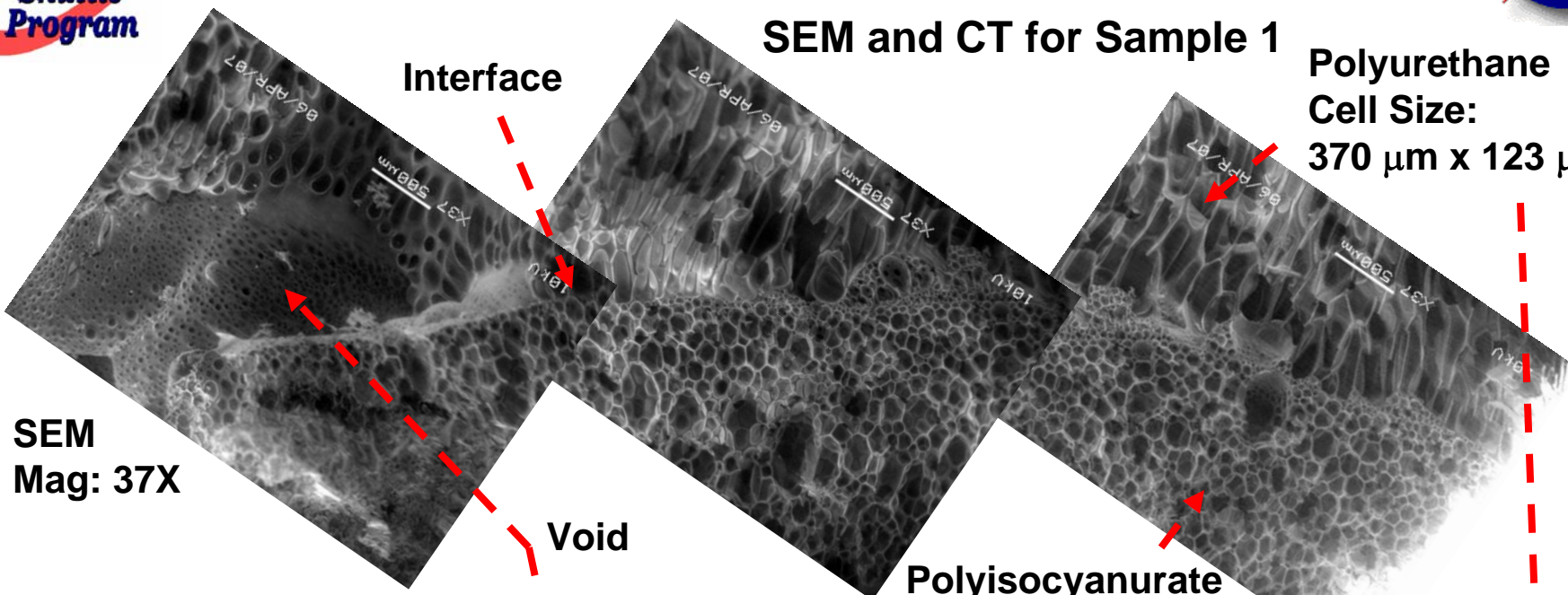


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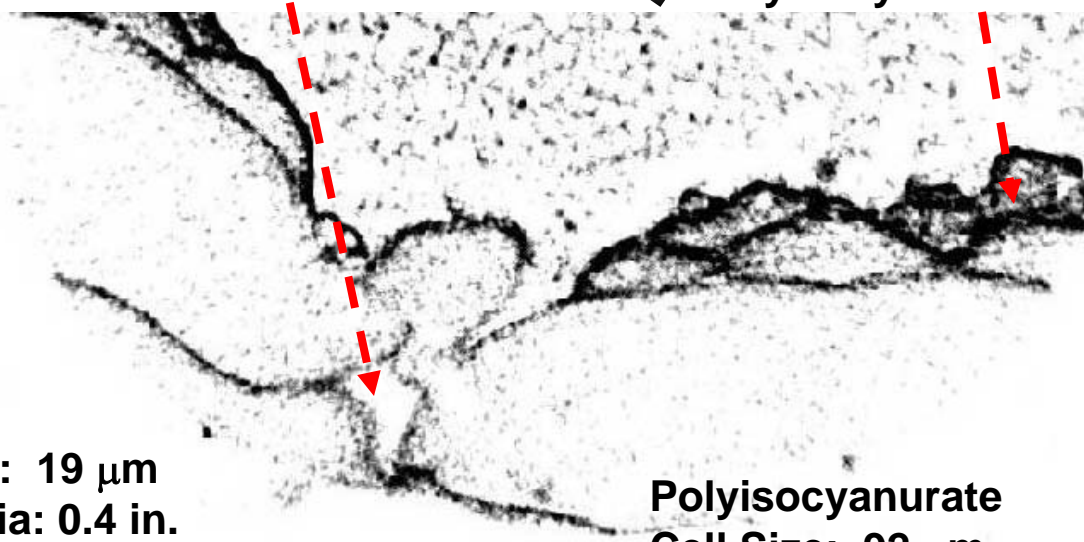


SEM and CT for Sample 1

Polyurethane
Cell Size:
370 μm x 123 μm



CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.



Polyisocyanurate
Cell Size: 92 μm

Void	Width	Length
	(μm)	(μm)
A1	321	513
A2	282	667

SEM and CT for Sample 1

Fine cells of
polyisocyanurate at interface

Interface

Polyurethane

SEM
Mag: 37X

Polyisocyanurate

CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.



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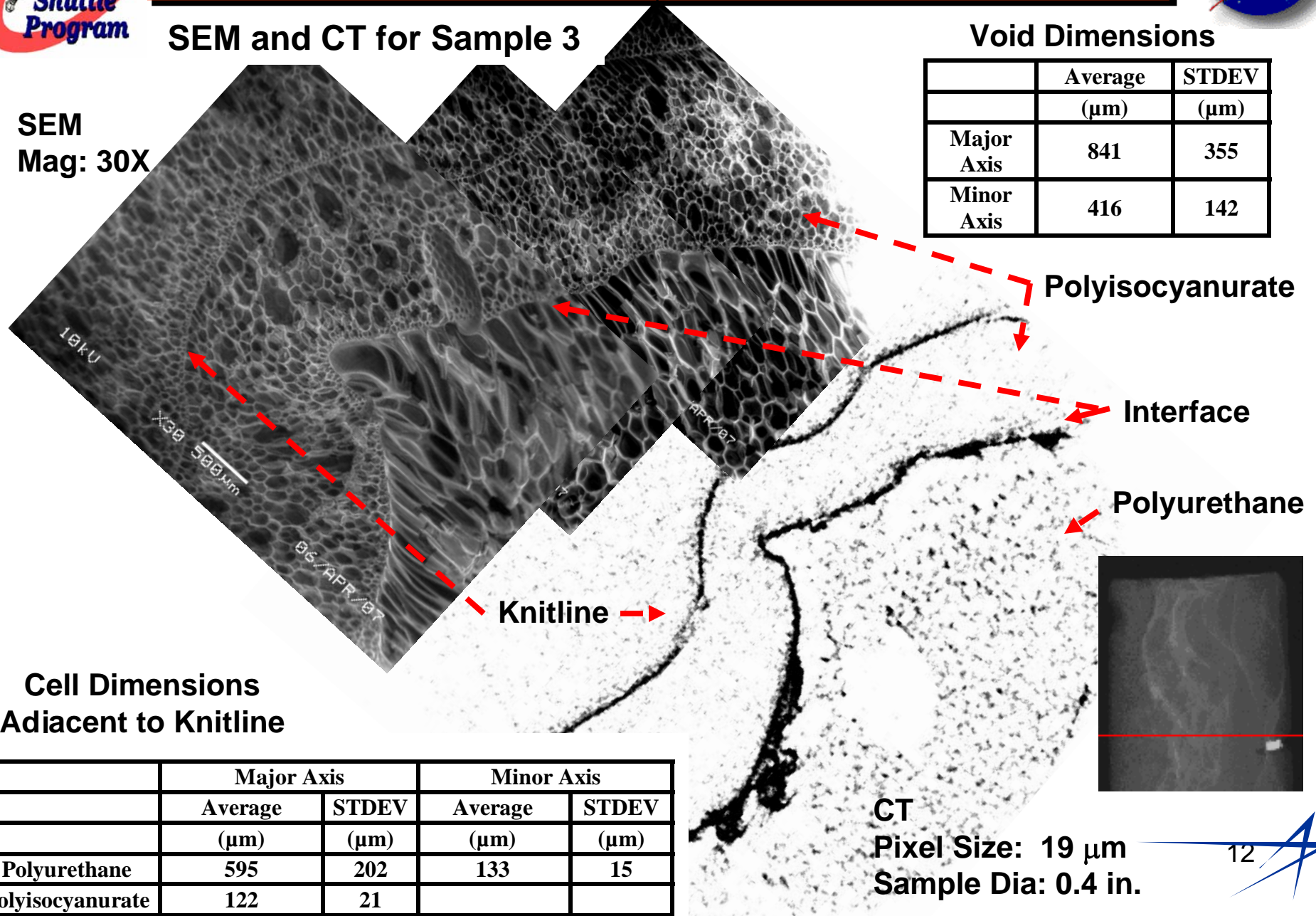


SEM and CT for Sample 3

Void Dimensions

	Average	STDEV
	(μm)	(μm)
Major Axis	841	355
Minor Axis	416	142

SEM
Mag: 30X

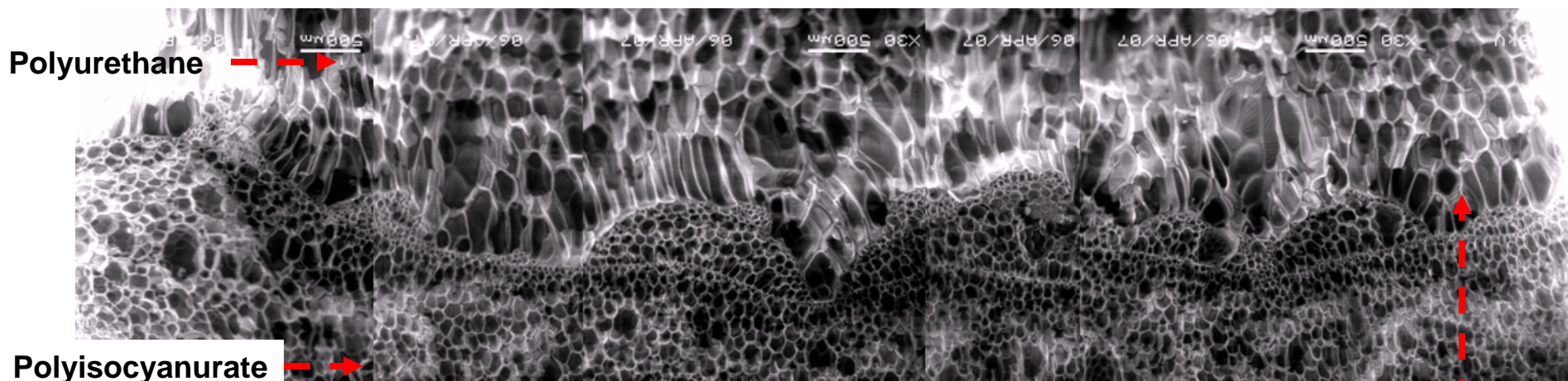


Cell Dimensions Adjacent to Knitline

	Major Axis		Minor Axis	
	Average	STDEV	Average	STDEV
	(μm)	(μm)	(μm)	(μm)
Polyurethane	595	202	133	15
Polyisocyanurate	122	21		

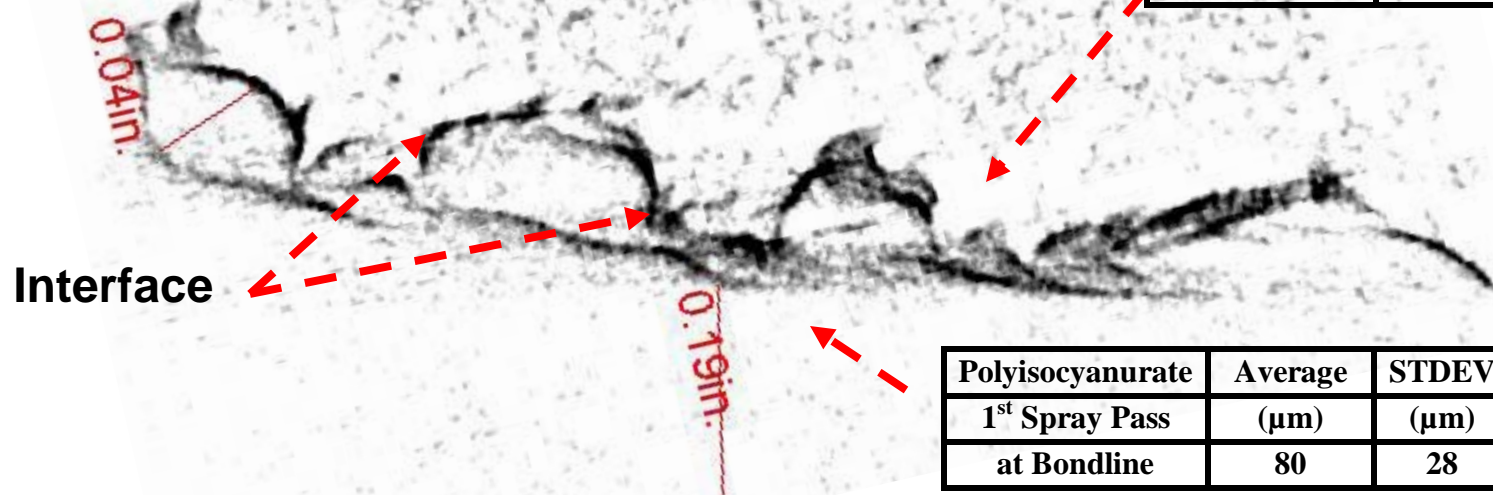
CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.

SEM and CT for Sample 5

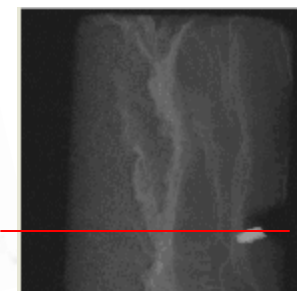


CT
Pixel Size: 19 μm
Sample Dia: 0.4 in.

Polyurethane at Bondline			
Major Axis		Minor Axis	
Average	STDEV	Average	STDEV
(μm)	(μm)	(μm)	(μm)
498	135	148	11

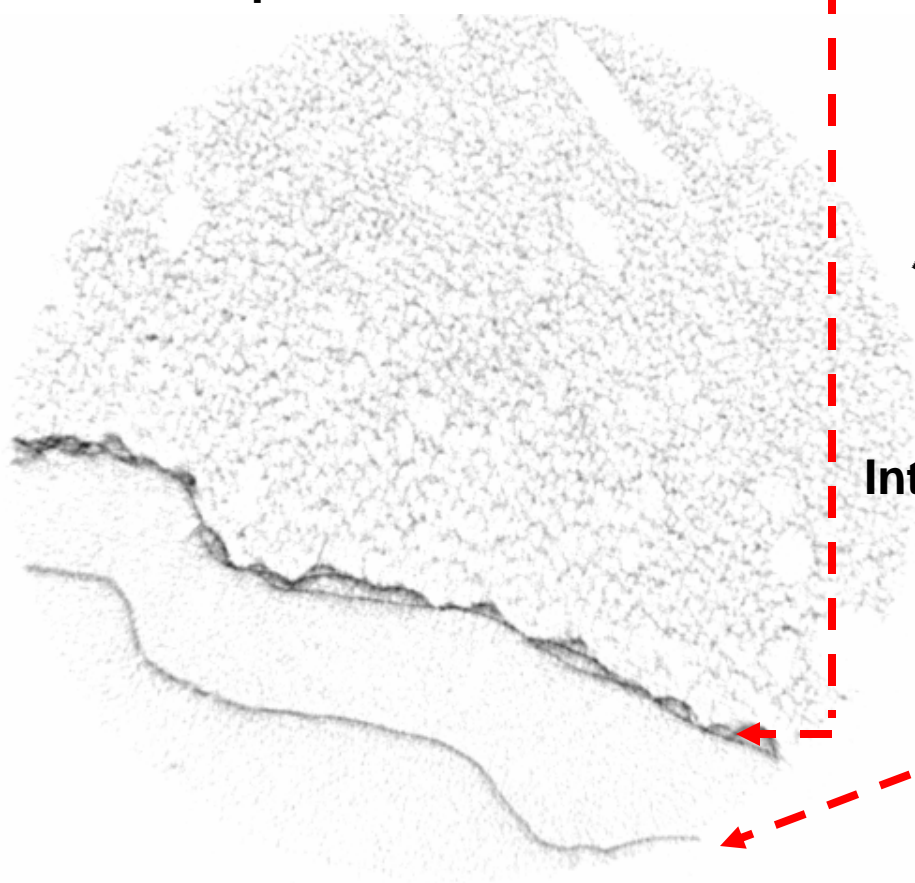


Polyisocyanurate	Average	STDEV
1 st Spray Pass	(μm)	(μm)
at Bondline	80	28



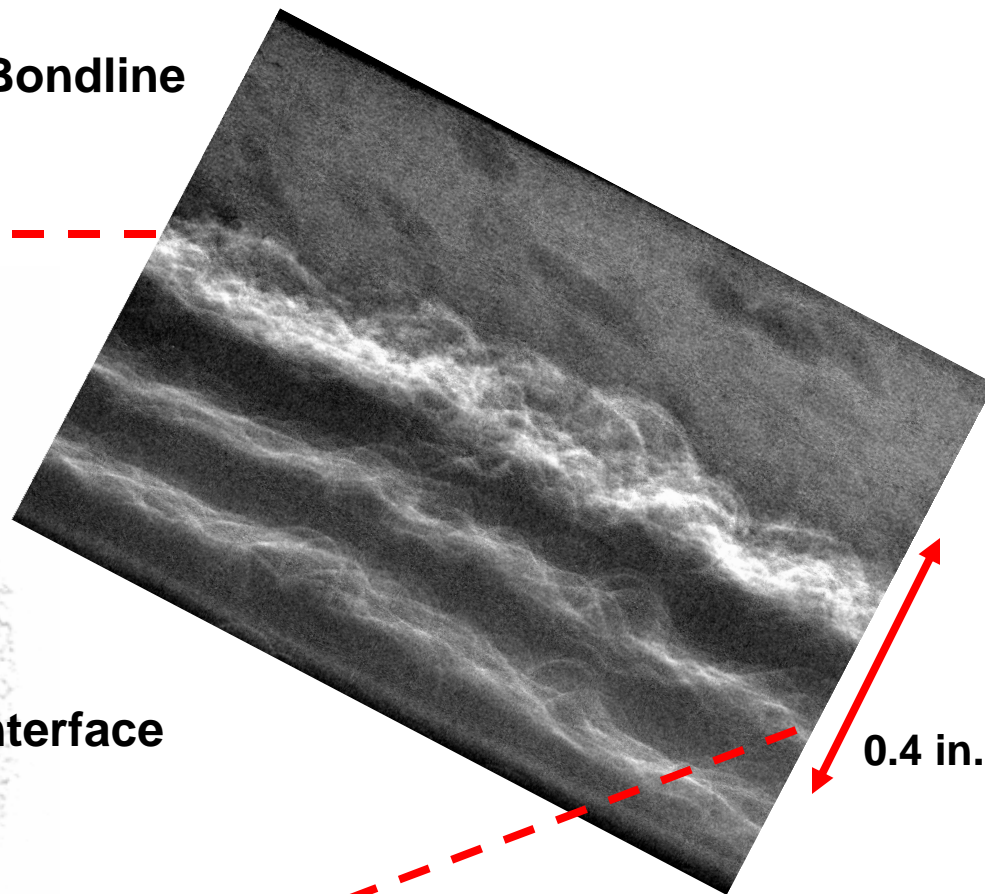
Typical Micro-CT Cross-Section of Bondline

- Pixel Size: 19 μm
- Sample Dia: 0.4 in.



Interface

Knitline



0.4 in.

Digitized Radiograph
Pixel Size: 50 μm
55kV, 6.5mA

Successive Micro-CT Cross-Sections





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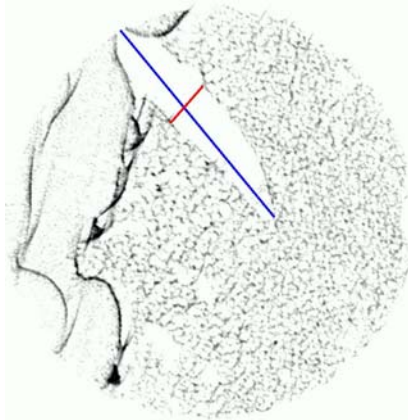
Micro-CT Cross-Section of the Largest Void Identified in Four Samples

Sample ID	Void Length (mm)	Void Length (in.)
1	8.81	0.347
2	3.24	0.128
3	3.03	0.119
4	4.54	0.179

Sample ID	Void Width (mm)	Void Width (in.)
1	1.53	0.060
2	1.56	0.061
3	1.35	0.053
4	1.60	0.062

Sample ID	Void Volume (mm ³)	Void Length (in. ²)
1	34.4	0.053
2	21.1	0.033
3	4.2	0.007
4	8.4	0.013

Sample 1

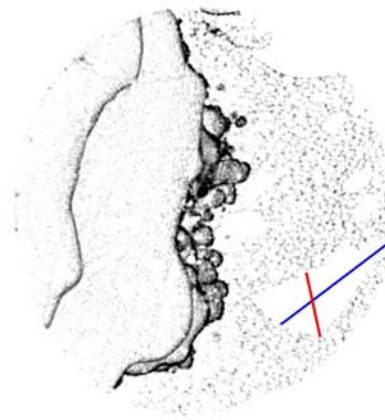


Lengths:
8.81 mm
1.53 mm

256 slices thick
(4.88 mm)

Ellipsoidal
Volume:
34.4 mm³

Sample 2

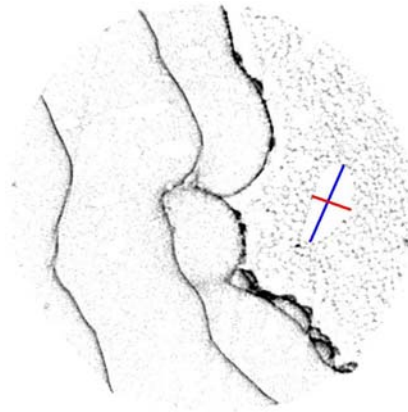


Lengths:
3.24 mm
1.56 mm

420 slices thick
(8.01 mm)

Ellipsoidal
Volume:
21.1 mm³

Sample 3

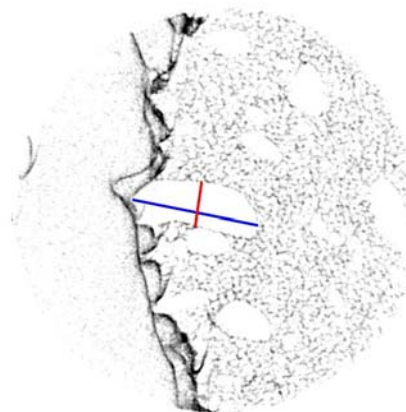


Lengths:
3.03 mm
1.35 mm

104 slices thick
(1.98 mm)

Ellipsoidal
Volume:
4.2 mm³

Sample 4

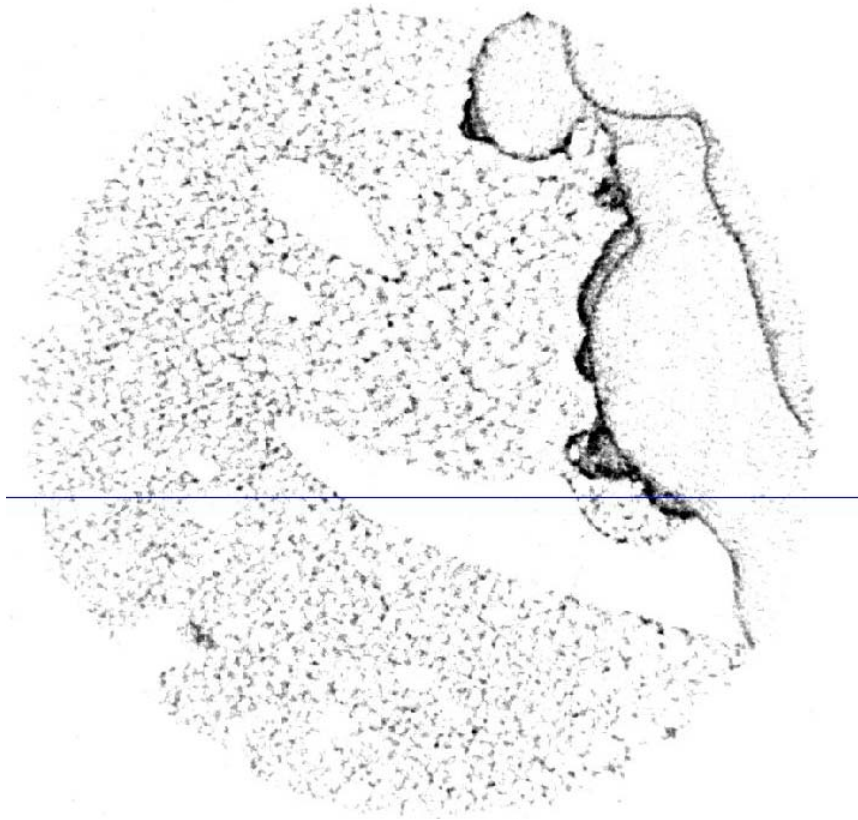


Lengths:
4.54 mm
1.60 mm

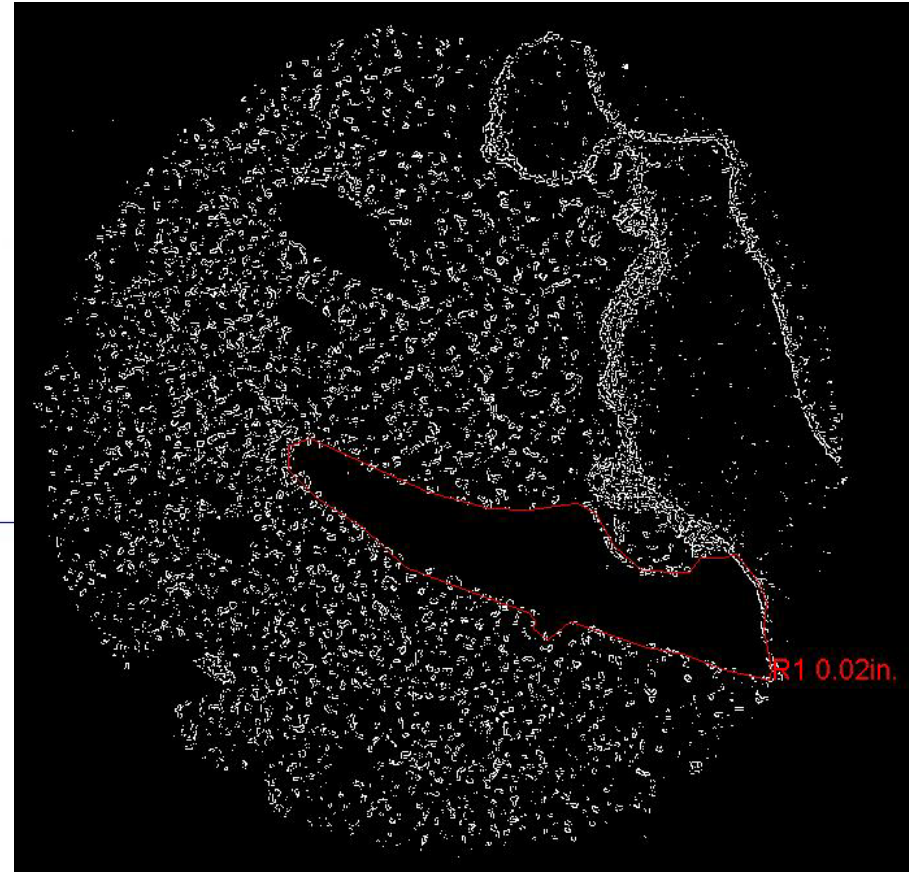
116 slices thick
(2.21 mm)

Ellipsoidal
Volume:
8.4 mm³

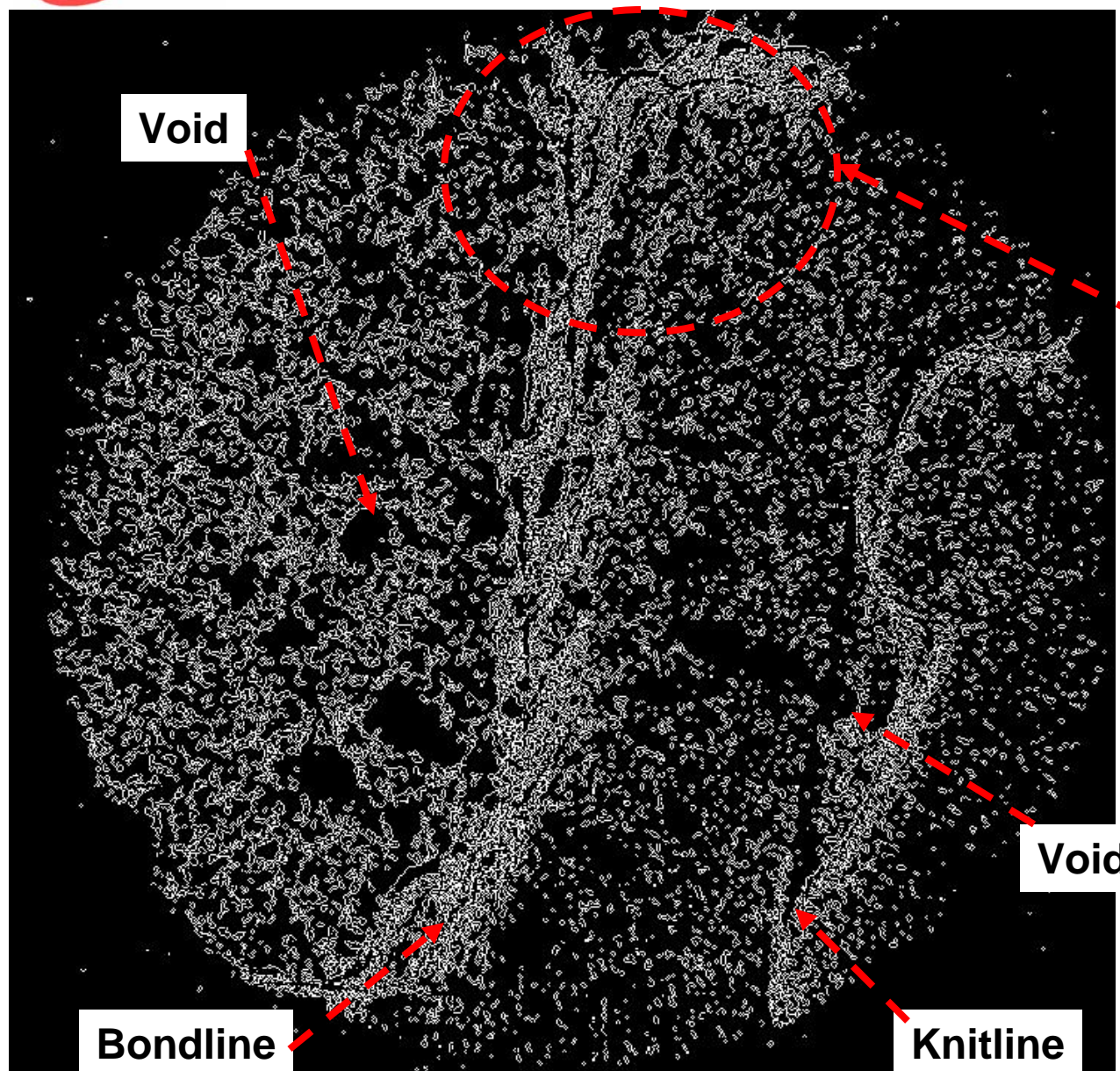
2D Visualization of Micro CT Image Enhanced with X-Ray GUI



CT Bit Map



**Robert's Edge Detection
with Measured Void
Area = 0.02 in.**



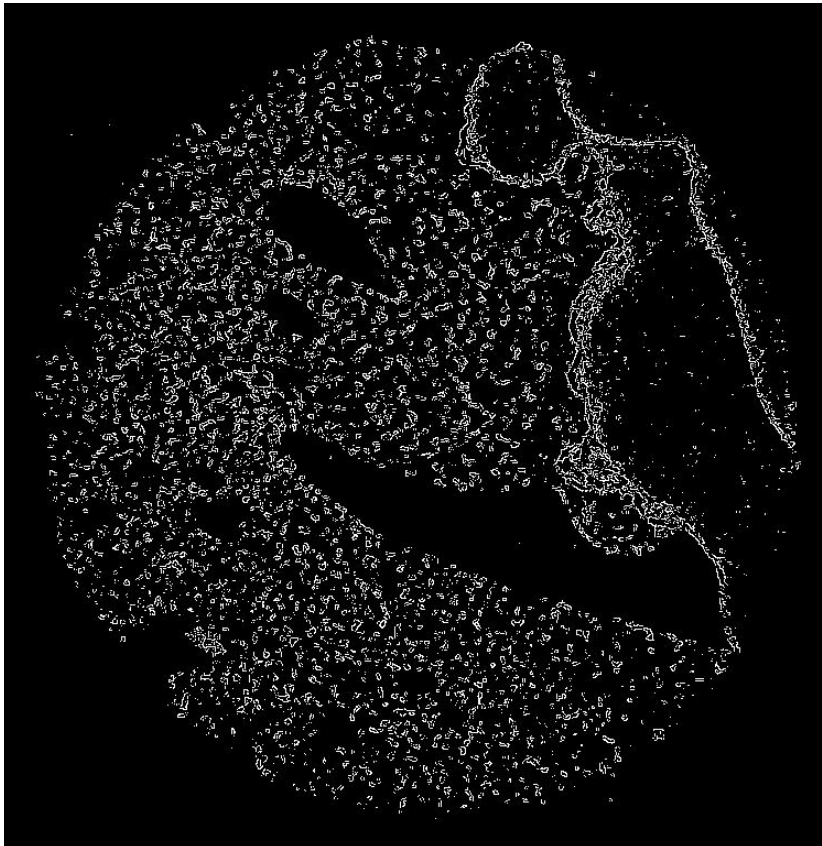
LaPlacian Edge Filter

- Bondline and voids
- X-Ray GUI filtered CT bitmap
- Pixel Size: 19 μm

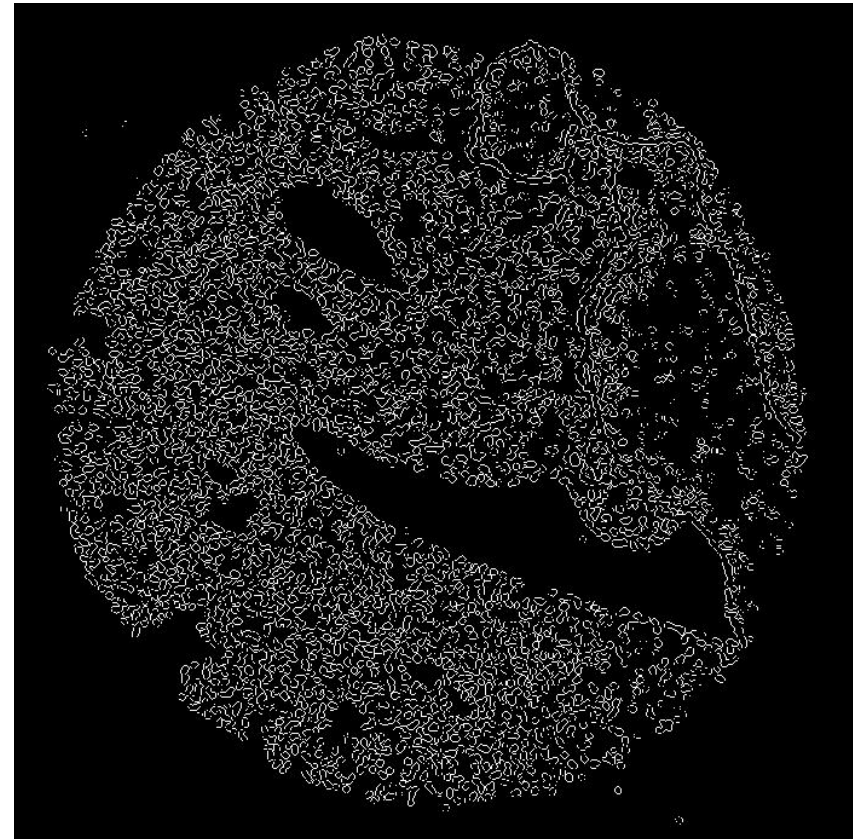


Micro-CT
Image with
Inverted Contrast

Edge Detection Technique Comparison for Micro CT Images

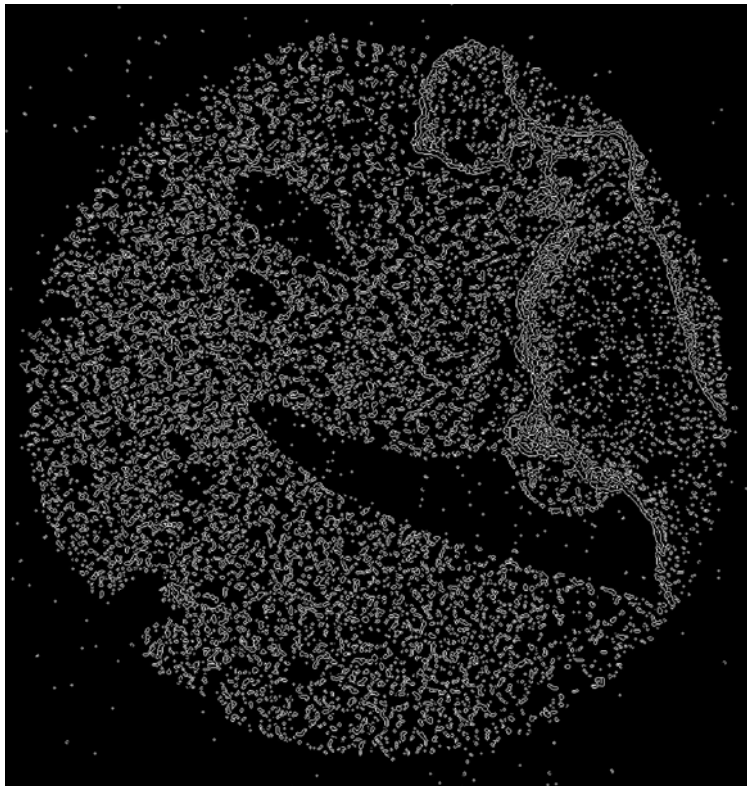


Robert's Edge Detection

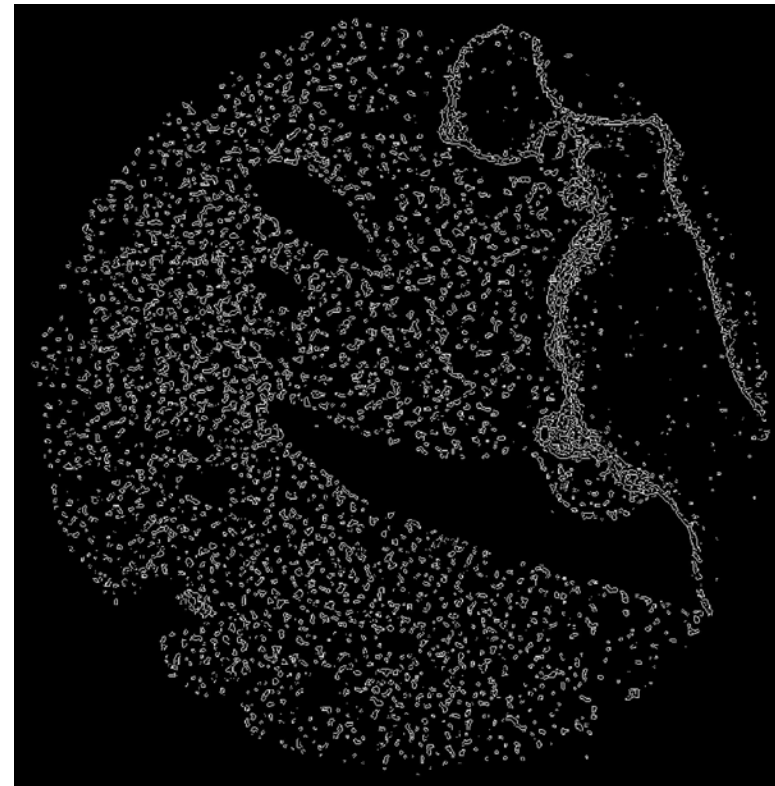


LaPlacian Gaussian Edge Detection

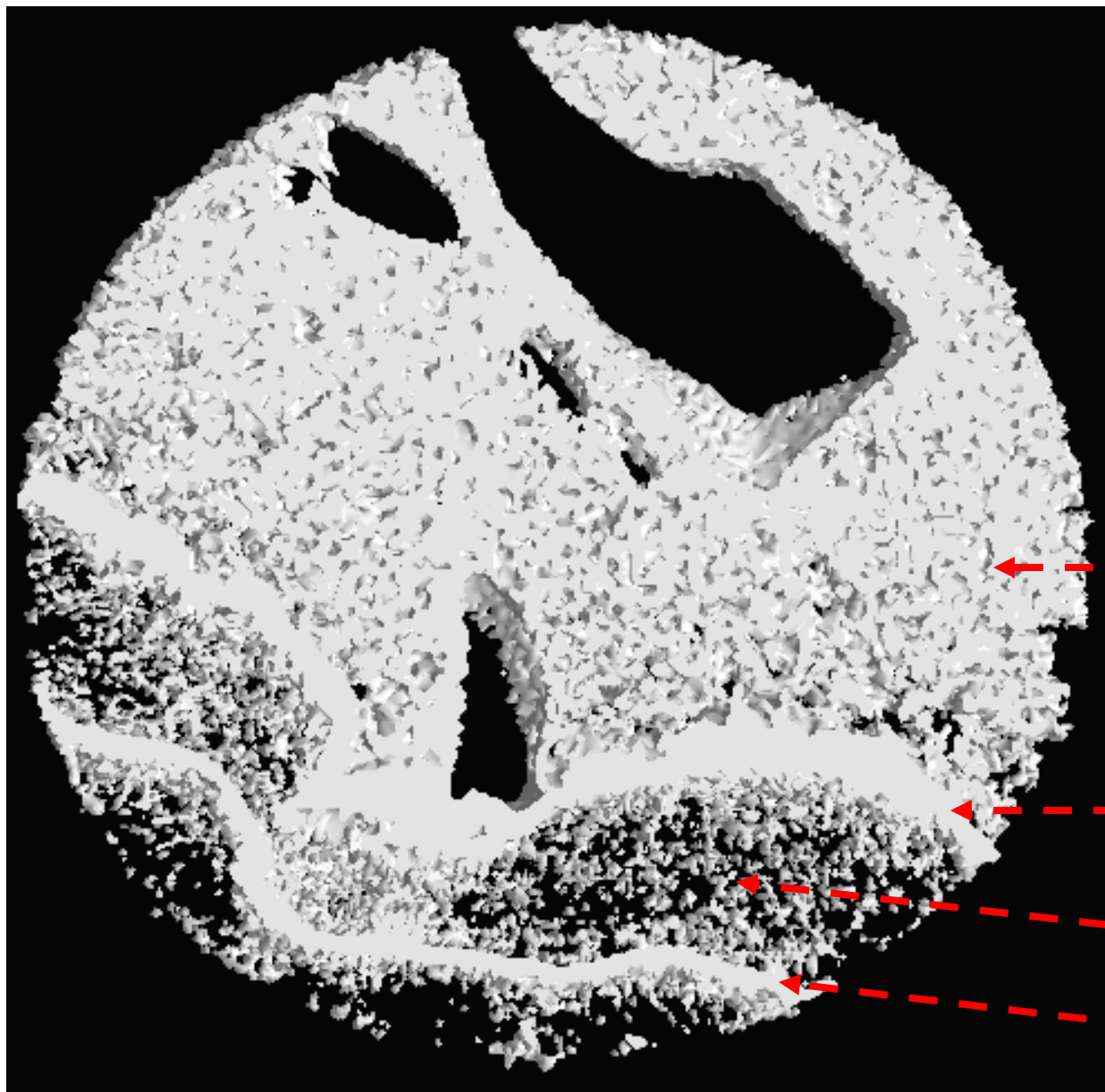
Edge Detection Technique Comparison for Micro CT Images



Canney Edge Detection



Sobel/Prewitt Edge Detection



3D Visualization
with
Skyscan 3D Creator

Pixel Size: 19 μm

← Polyurethane

← Bondline

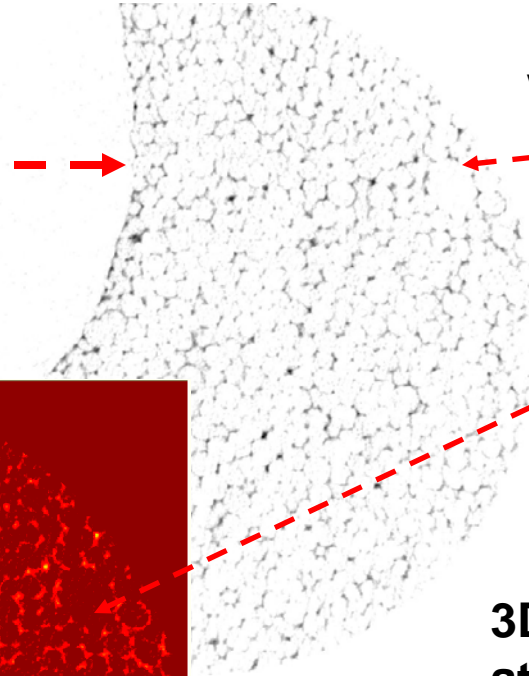
← Polyisocyanurate

← Knitline

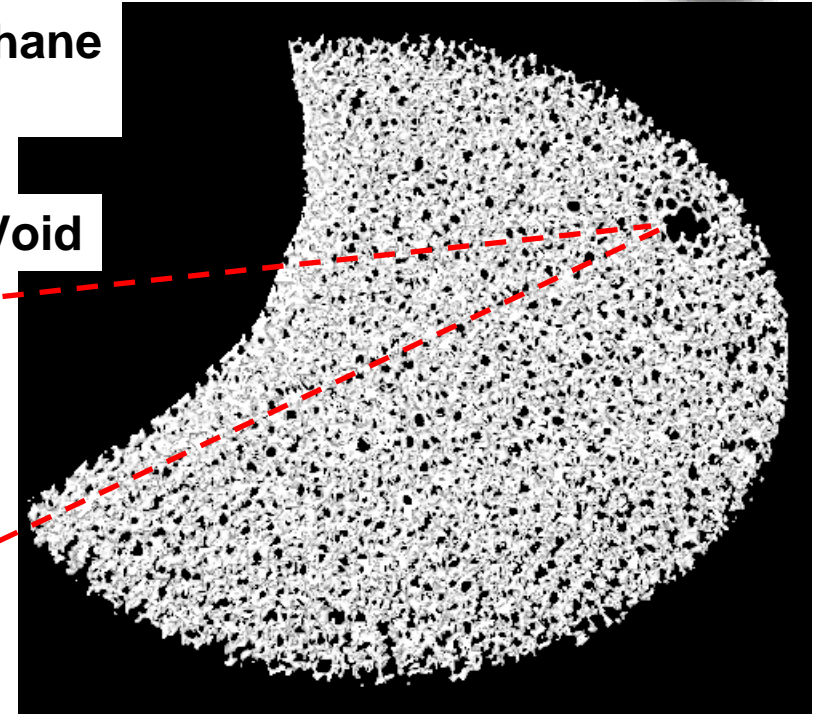


2D and 3D Visualization for Polyurethane CT Sample

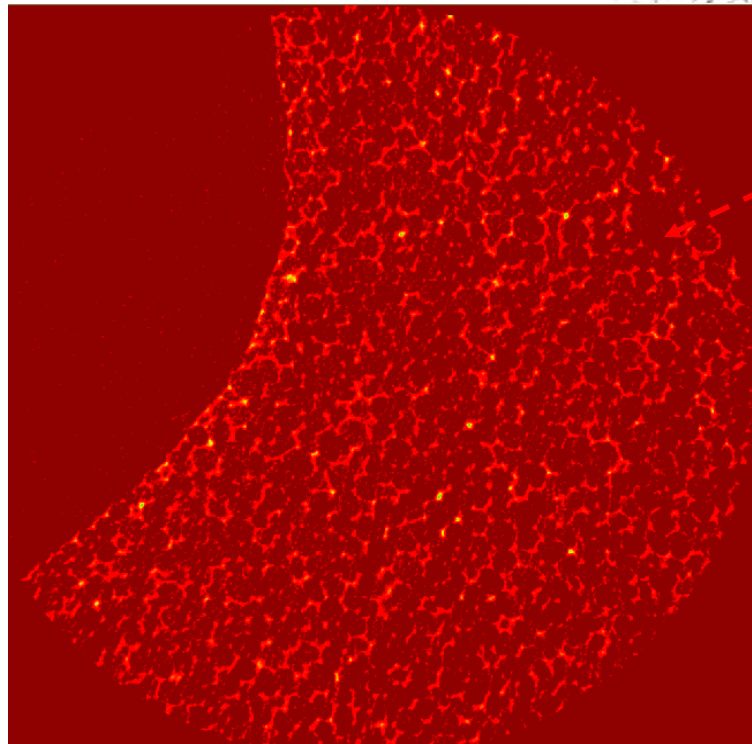
2D CT bitmap
resolved using
X-Ray GUI



Void



3D visualization of polyurethane
at a void constructed with SKYScan
3D Creator

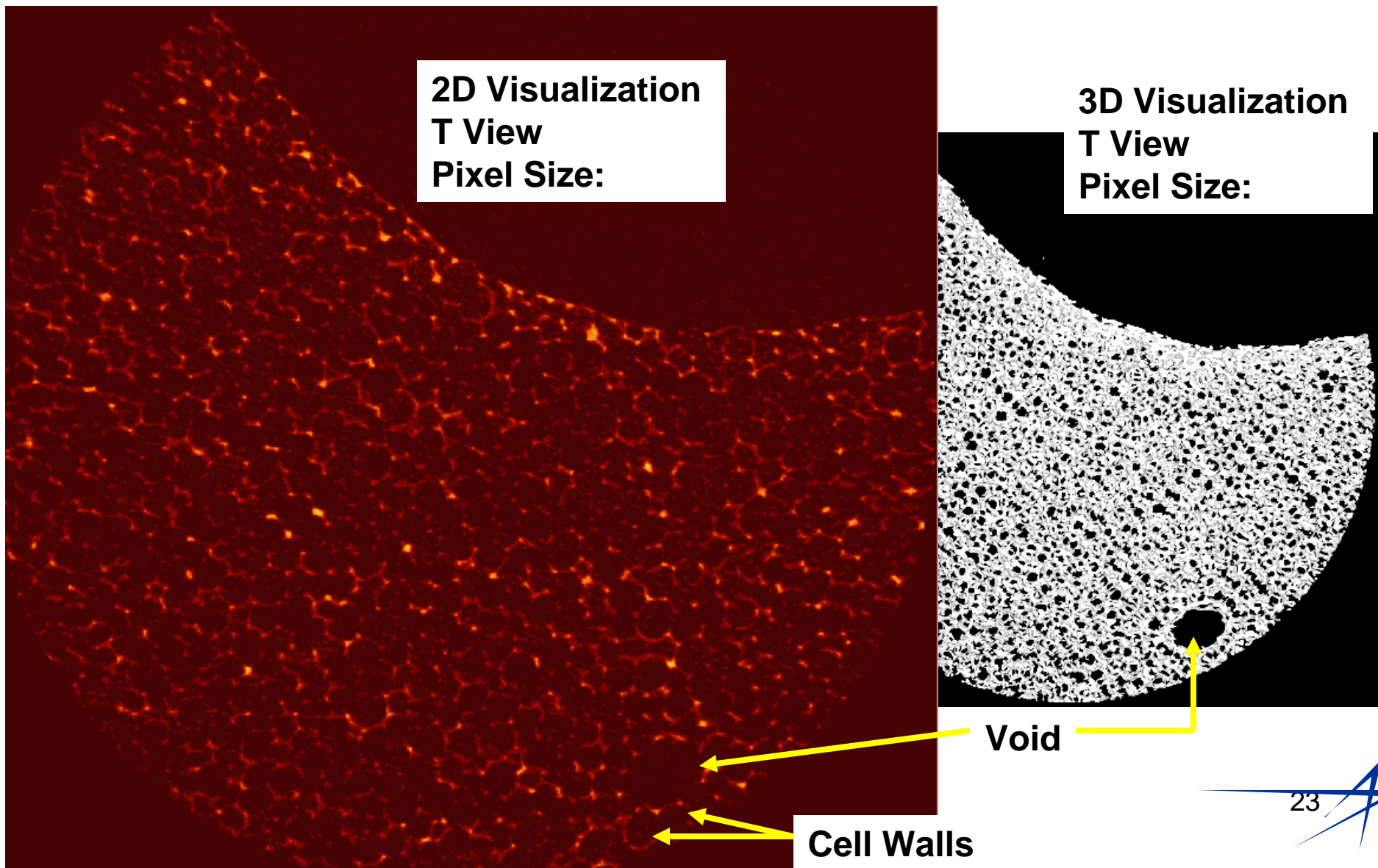


2D CT bitmap with inverted color
resolved using T View

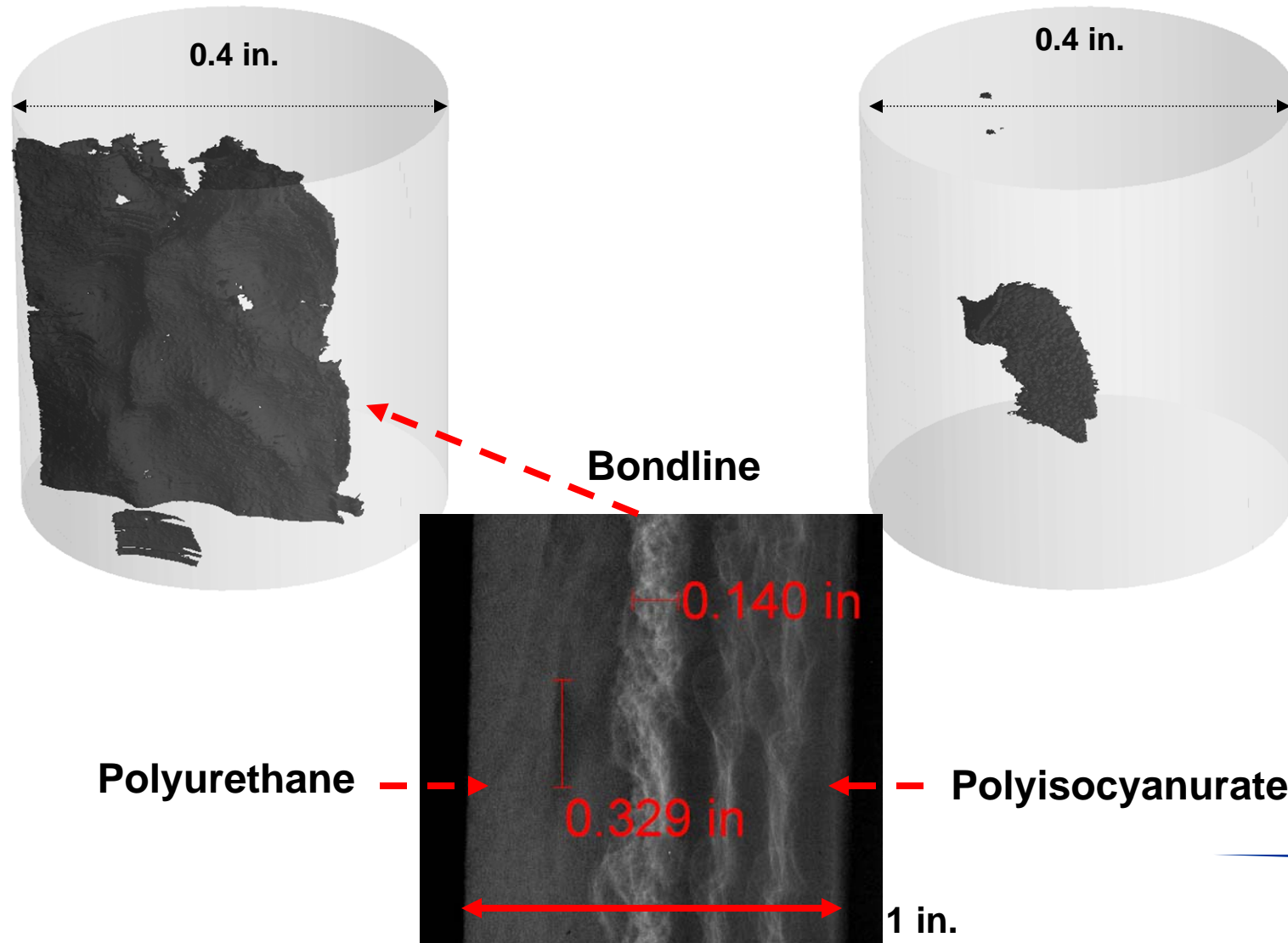
2D and 3D Visualization for Polyurethane CT Sample

2D Visualization
T View
Pixel Size:

3D Visualization
T View
Pixel Size:

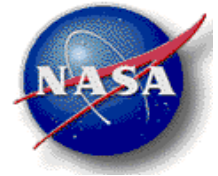


2D Radiography and 3D Visualization of Bondline Interface and Void





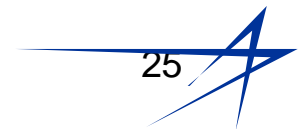
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3D Visualization of Bondline Interface and Void



Created with a 3D model of Figure 10
Figure 10: A 3D model of a bondline interface and void.



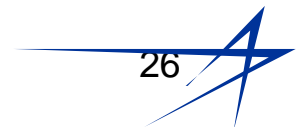


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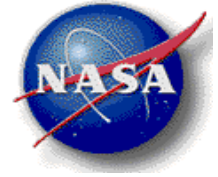
Conclusions

- **Micro-CT provided detailed characterization of polyurethane-polyisocyanurate foams and their interfaces**
- **The major morphological features - foam cells, voids, knit lines, and the bondline interface were evaluated**
- **The features identified by micro-CT correlate well to those observed by SEM**
- **3D reconstructions yielded volumetric dimensions for large voids (max ~ 30 mm)**
- **Internal voids and groupings of smaller cells at the bondline are concluded to be the cause of the indications noted during the NDE prescreening process**



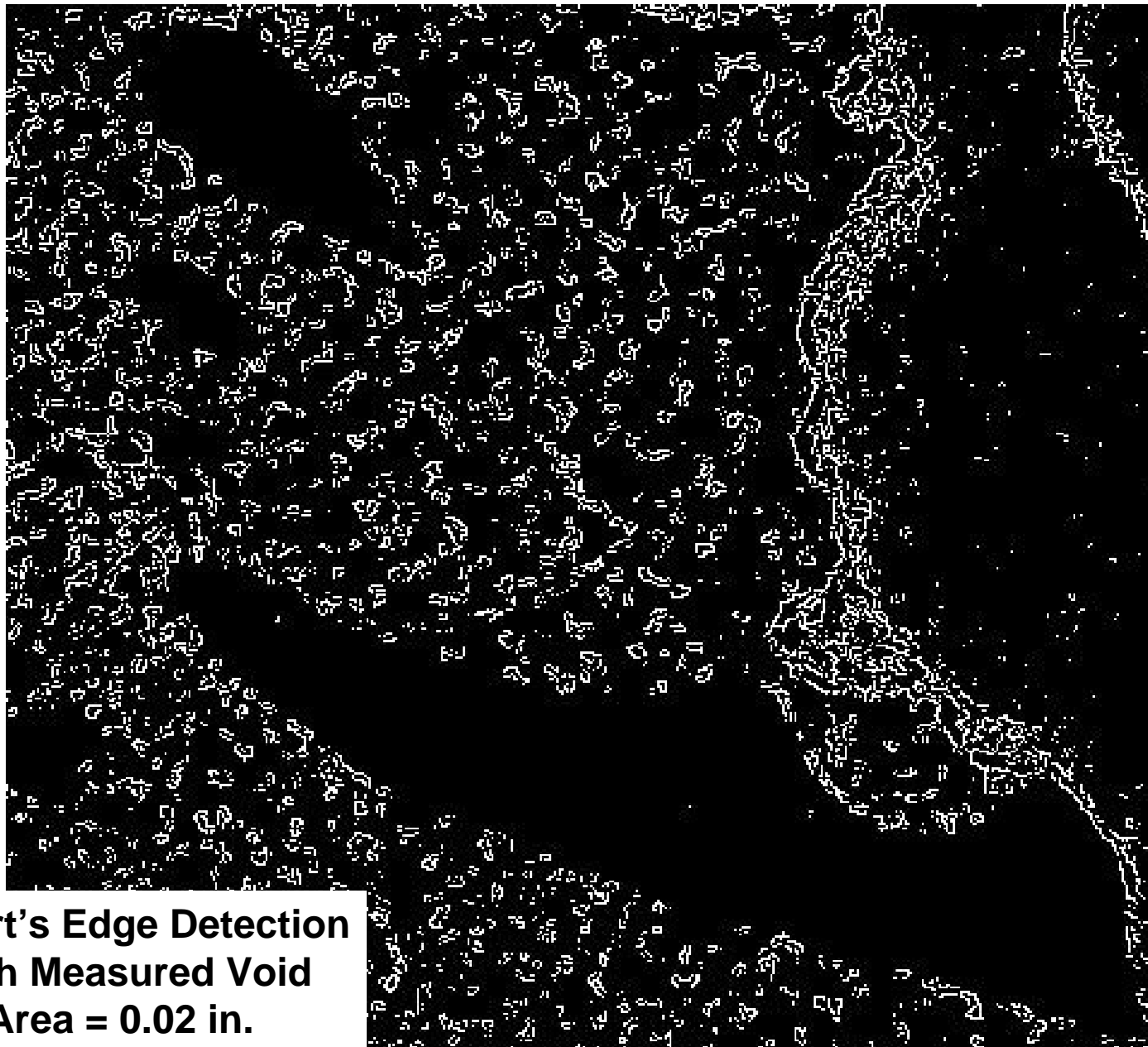


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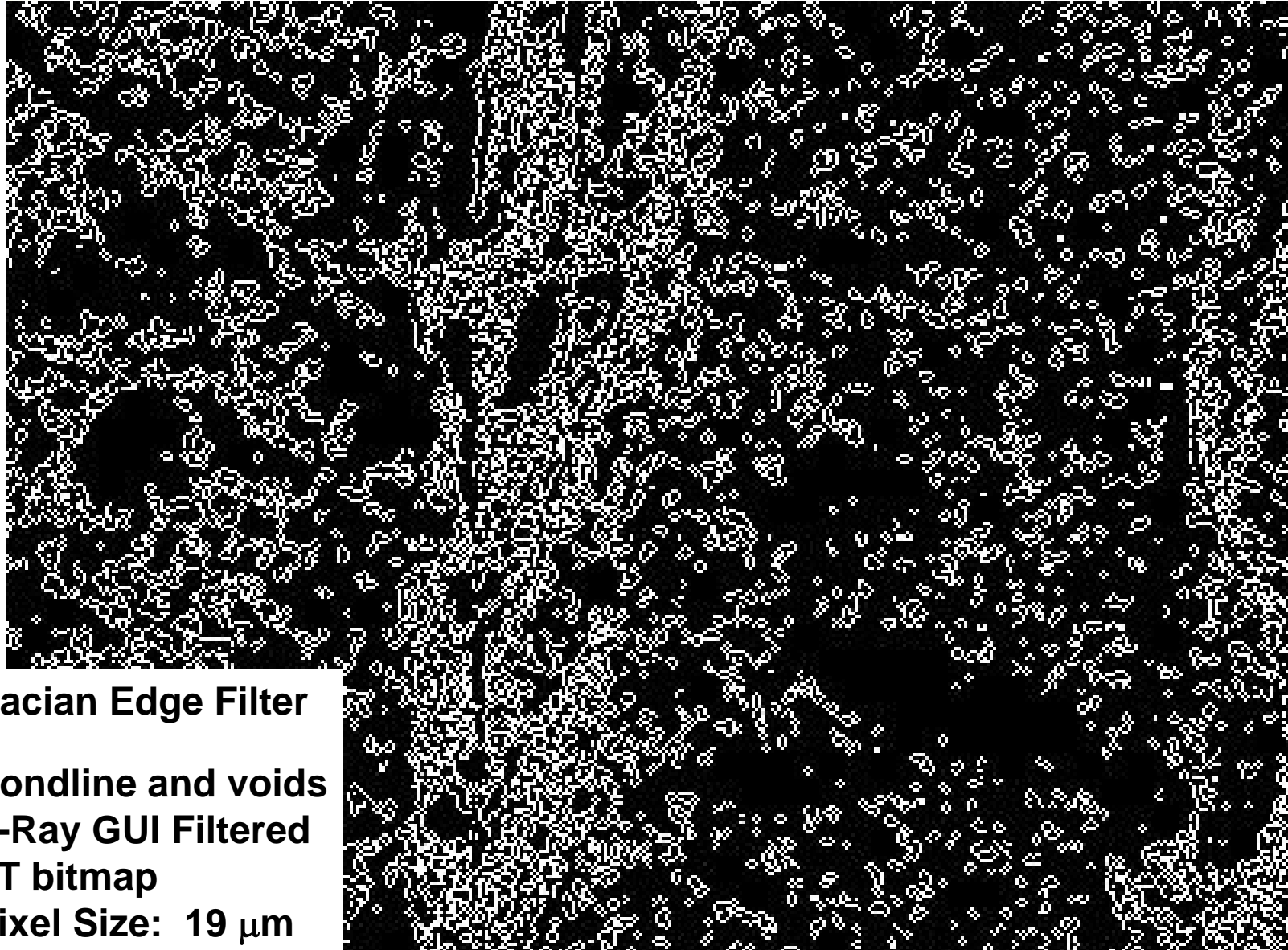
Back Up

Applications of Computed Tomography to Evaluate Cellular Solid Interfaces



Robert's Edge Detection
with Measured Void
Area = 0.02 in.





LaPlacian Edge Filter

- Bondline and voids
- X-Ray GUI Filtered CT bitmap
- Pixel Size: 19 μm